OVERVIEW OF RESEARCH ON GRAPHENE-BASED MEMBRANES : OPPORTUNITIES & CHALLENGES

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Graphene, the atomically thin monolayer of carbon atoms, has received wide attention in recent years. From the perspective of membranes, graphene, is an exciting material. Given that permeation speed scales inversely with the thickness of a membranes, a monolayer of atoms, at least conceptually promises the lowest possible transport resistance. However, graphene, in itself is impermeable, so several studies have shown methods to 'drill' well-controlled nanometric or smaller holes with large density (~10^{12} cm^2) in single layer graphene. These membranes have shown molecular sieving properties and also expectedly, fast mass transport properties; selectivity is however controlled by the size of the nanometric pores and hydrodynamic entrance effects. Graphene membranes can also be formed by stacking of sheets of graphene-oxide. The procedure is relatively simple and there are possibilities of scaling up rather easily. However, compared to the single-layer graphene membranes, the permeability is a strong function of the number of layer that are stacked as well as the structural order of the assemblies. Transport through this labyrinthine structure is quite complex and many factors determine the permeability/selectivity properties such as the interlayer gallery distance, presence of defects and proportion of sp2 (graphitic) and sp3 bonds (carbon-oxygen), and even the presence of adsorbed water inside the graphene-oxide channels. Several promising applications for these types of membrane have been demonstrated such as molecular sieving typically in the 400-1000 Da molecular weight range, selective permeation of water vapour over organic components such as ethanol leading to pervaporation-type separations. The advantages of membranes produced by this approach has the best of both the worlds - they can be processed like polymers, yet has the chemical inertness of carbon which means that these membranes have potential for applications in harsh chemical environments such as extreme pH or temperature as well as survival in aggressive chemical cleaning protocols. These developments have led to an explosive growth in the field of graphene-based membranes.

Many challenges still remain: understanding the transport properties are essential to develop reliable applications, controlling the inter-layer gallery distance both increasing and decreasing the size to tune the molecular weight cut-off, and improving methods to produce these membranes in commercially attractive scales are just a few of them. With methods to produce graphene or graphene oxide reasonably established and being produced in industrial scales and realizable application demonstrated, the future of the field is bright.